ISSN 2229-5518

Design and Fabrication of a Small-scale CNC Milling Machine

Phyo Wai Lin

Abstract— This paper reports the design and fabrication of small-scale CNC milling machine which is capable of 3-axis simultaneous interpolated operation. The idea behind this work is to design low cost and easy portable machine which is achieved by incorporating the features of a standard PC interface with ATMEGA 328 micro controller based CNC system in an Arduino. The system also features an offline G-Code parser and then interpreted on the micro-controller from a USB. The main objective of this work is the development of a model of CNC machine on educational purposes. The design CNC machine with workspace of 150mm ×150mm using a precision stepper motors that combined with lead screws in moving the axis smoothly on linear bearings that increases a more precisely results obtained.

Index Terms— CNC Milling, G-code, Arduino, Stepper motor, Linear Bearing

1 Introduction

COMPUTER Numerical Control (CNC) is the automation of machine tools that are operated by a computer controlled programs to perform a desired product shape. In modern CNC systems, product design is made with computer-aided design (CAD) and is created computer-aided manufacturing (CAM) programs. The programs produce a computer file that is interpreted to extract the commands needed to operate a particular machine via a post processor, and then loaded into the CNC machines for production [1]. With the ongoing development of technology and economy, new industrial requirements such as high precision, good quality, high production rates and low production costs are increasingly demanded. Most of such requirements, including dimensional accuracy, conformance to tolerances of finished products and production rate can be met with better machine tools. With the help of CNC technology, machine tools today are not limited to human capabilities and are able to make ultra-precision products down to nano scales in a much faster manner [2].

The require for a G-code parser using an Arduino based microcontroller which is integrated part of the system, is offline, a huge reduction in the cost price is achieved, as a result making the system inexpensive for small scale industries and individuals [3].

Fabrication of CNC milling machine is used low-price milling cutter for the main spindle due to a low voltage supply and it is possible to use the tools of smaller dimension to machine materials like wood, aluminum and plastic materials. There are several advantages of using small machines to produce small sized objects. With a smaller machine size, space is saved. The energy required to operate the machine is reduced as well [4].

This paper focuses on how to build a small size CNC machine that is, fully functional, easy to maintain and inexpensive. The main components used to build the machine are stepper motors, controller board, stepper motor drivers, lead screws, motor shaft coulpings and limit switches.

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2 Methodology

The CNC machine is constructed in three stages: (a) build mechanical frame, (b) assemble electric system and (c) install control and computing system. Mechanical system gets necessary control signals from electronics system which ultimately results in desired actuation of motors. Electronics system gets command or a set of commands from software system and generates controls for mechanical system. The block diagram of the CNC machine system is shown in Fig.1.

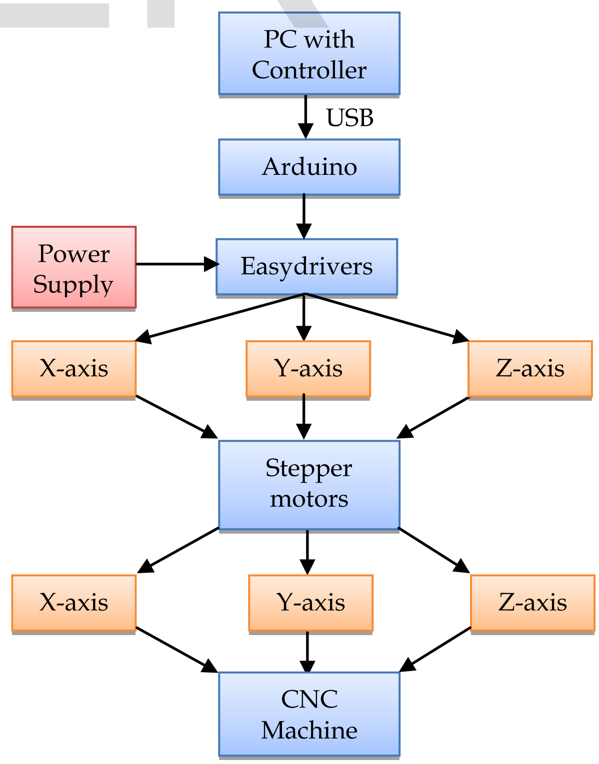


Fig. 1. Block diagram for CNC machine system

3 CNC Milling Design

The modeling of the CNC machine was created using AutoCAD software. By calculating of the torque for required tast suitable stepper motor was selected and structure material used to build the prototype include machine mild steel plate 4 mm thick. Machine structure is the "backbone" of the machine tool. It integrates all machine components into a complete system. The machine structure is crucial to the performance of the machine tools since it is directly affecting the static and dynamic stiffness, as well as the damping response of the machine tool. A carefully designed structure can provide high stiffness, result in higher operation bandwidth and more precise operation. A small-scale machine tool generally requires even higher stiffness than the ordinary large-scale machine tool since it is usually operated at higher speeds. This structure consumes less material, hence is very less expensive to build. The guide rods are selected to provide accurate motion for the machine, and are strong enough to support the weight of the machine table and all of the equipment mounted to it. The Z-axis guiding system will usually be smaller than the other two axes, because it only has to carry the weight of a small carriage and cutting tool.

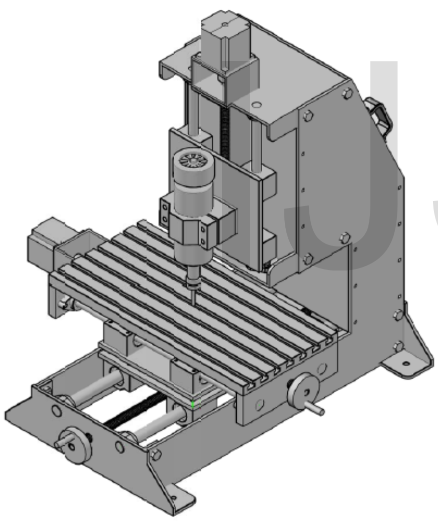
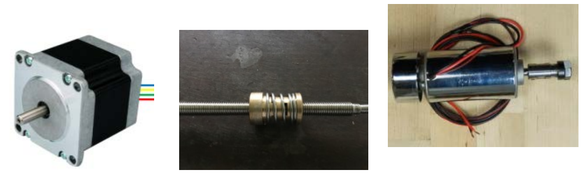


Fig. 2. A CAD model of CNC milling

3.1 Mechanical System

The mechanical system is assembled in such a way that the 3-axis movement is achieved by using the linear bearings and guide rods. Stepper motors are mounted to the each axis which is the source of motion acted according to the control signal generated from the electronics circuit. Each stepper motor is coupled to the screw rod which carries nut with the help of coupling bush. This screw rod and nut arrangement is responsible for converting the rotational motion of the stepper motor to linear motion. The linear motion of each axis is carried away smoothly by the linear bearing and guide rod assembly connected to the each axis which is capable of load carriers and allows linear motion in each axis. The controlled motion in each axis is achieved directly by controlling the rotation of the stepper motor. The speed of the motion in each axis can also be controlled by direct control of the speed of the stepper motor by giving required control signals. Thus the tool path of the spindle fixed to the end effector is controlled in each axis for smooth carving or cutting action of work piece.



(a) (b) (c)

Fig. 3. Components of the machine: (a) stepper motor, (b) lead screw and nut, (c) spindle motor

Linear rods are rigit strong steel shafts which are used to carry the load with out affecting the motion and supports linear movement. The load is carried away by the linear bearing and reduces friction slides over linear rods.

Fig. 4. Linear rail assembly (linear rods, linear bearings, end shafts)

3.2 Electrical System

Arduino uno r3 is selected to be the control unit in this project. The arduino uno is a microcontroller board based on the ATmega328 chip. The microcontroller board is flashed with G-code interpreter code which was written in the C language. The control board is responsible to generate the control signal for corresponding command signal from the computer to the stepper motors which is directly controls the motion of the tool path. Fig. 4. displays the functionally of the Arduino pins as used by GRBL. The driver called easydriver (Fig.6) is used as the stepper motor driver. It receives steps signal from microcontroller and convert it into voltage electrical signals that run the motor.

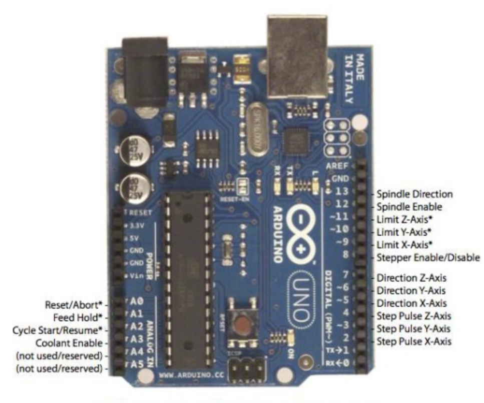


Fig. 5. Arduino uno CNC layout pins

ISSN 2229-5518

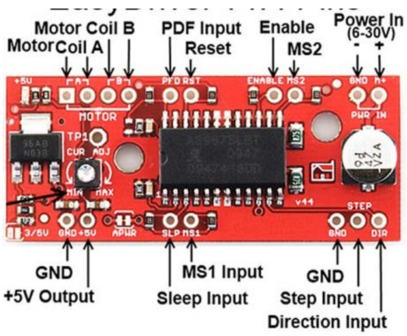


Fig.6. Easy driver V4.4 pins

Two power supply units are used for the electrical system of the machine. 24V DC Power supply is used for the stepper motors of three axes and 48V DC power supply is used for the spindle motor.

First, to connect the stepper motors to Grbl, it will need stepper motor drivers to power the steppers and connect the driver inputs to the Arduino controller pins. The step signal ground for each EasyDriver is connected together and tie to the GND pin of the Arduino. The 'Step' pin for the X, Y and Z axes is attached to digital pins 2, 3 and 4 respectively. The 'Dri' pin for the X, Y and Z axes is attached to digital pins 5, 6 and 7 respectively. Fig.6. shows the wiring diagram of the Arduino, EasyDrivers and stepper motor.

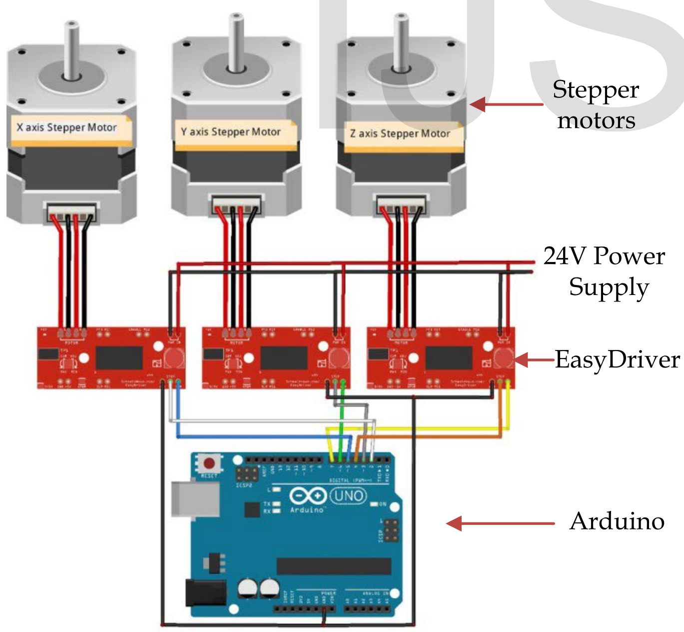


Fig.7. Wiring diagram of arduino, easydrivers and stepper motor

3.3 GRBLSoftware

GRBL is opensource software that runs on Arduino Uno that taks G-code commands via Serial and truns the commands into motor signals. GRBL source code is added to Arduino library and Arduino IDE is used to flash GRBL directly to the Arduino board.

Grbl Controller is software that is designed to send G-code to CNC machines, such as 3D milling machies. It just needs to give the user a nice way to get command down to whatever controller they are using. Grbl Contoller is written using the Qt cross-platform libraries. It also gets some help from the QextSerialPort library to simplify choosing the correct USB serial port.

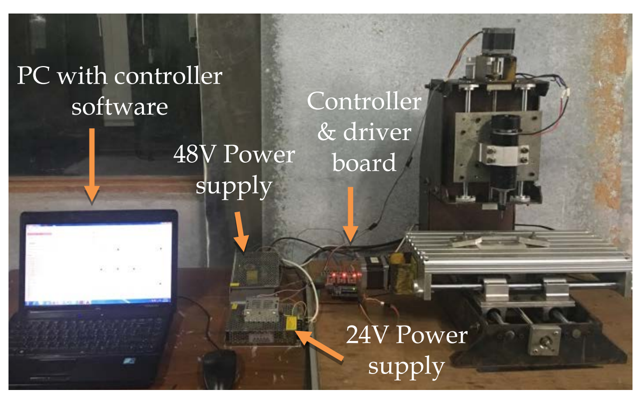
Fig. 8 Grbl Controller

3.4 Machine Specification

The technical parameters of the machine are shown in table 1 and the complete assembly of the CNC machine is illustrated in Fig. 8.

TABLE 1
TECHNICAL PARAMETERS

Machine dimension	500×500×650 (mm)
Working area	150×150 (mm)
Z-axis travel	100mm
Driver motor	Stepper motor, 1.8°/step
Spindle motor	500W, dc motor, 12000rpm
Feed rate	5 to 100 mm/min
Controller	PC based GRBL Controller
Chuck	ER11



International Journal of Scientific & Engineering Research Volume 9, Issue 8, August-2018 1207
ISSN 2229-5518

Fig. 9. Complete assembly of CNC milling machine

4 Results and Discussion

4.1 Accuracy and repeatability

In this work, M12 leadscrews are used for the linear movements of the machine axis. The pitch of the leadscrew is 1.75 mm. 1.8°/step stepper motors are used as the drive motors in this machine. The first thing is to have step/mm required for the stepper. The easydriver is in 8 steps microstepping mode. It is clearly to calculate the step/mm by the following.

$$\text{Steps/mm} = \frac{360°/\text{revolution}}{1.8°/\text{step}} \times \frac{1}{1.75\text{mm/rev}} \times 8$$

$$= 914.288 \text{ steps/mm}$$

So the steps to move one millimeter is 914.288 steps/mm. The accuracy of the machine for X and Y axes is test with the dial gauge. The results are in each repeated measurement been held is not only testing the stepper motor accuracy but it is the whole system is perfectly accurate.

Table 2 and 3 show the result measurements in five repeated tests using dial gauge. Fig. 12 and 13 show how was the axes are accurate in each repeat X and Y axes readings are given table 2 and 3.

TABLE 2
X-AXIS REPEATED DATA

Test	Measurements (mm)
1st test	10
2nd test	10
3rd test	9.99
4th test	10.01
5th test	10

TABLE 3
Y-AXIS REPEATED DATA

Test	Measurements (mm)
1st test	10
2nd test	10
3rd test	9.99
4th test	10.01
5th test	10

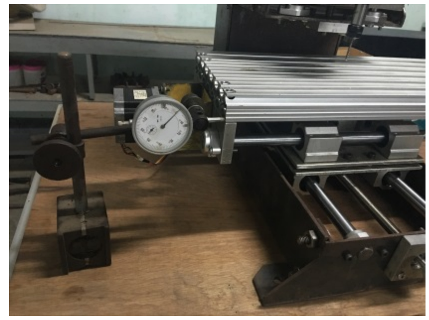


Fig. 10. X-axis experiment with dial gauge

Fig. 11. Y-axis experiment with dial gauge

The experiment measurement results are shown in Fig. 12 and Fig. 13 as the graphical reperesentation.

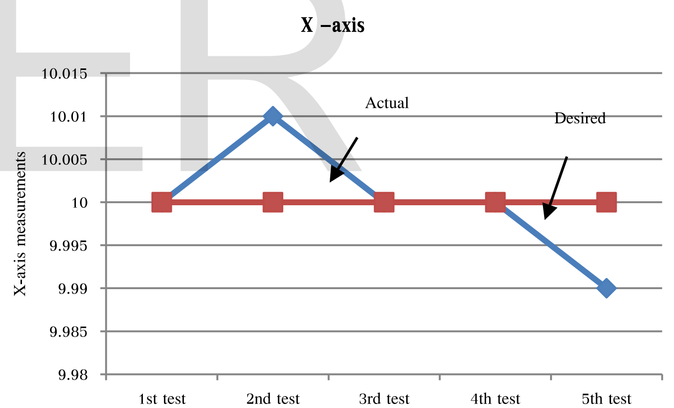


Fig. 12. X-axis mesurements

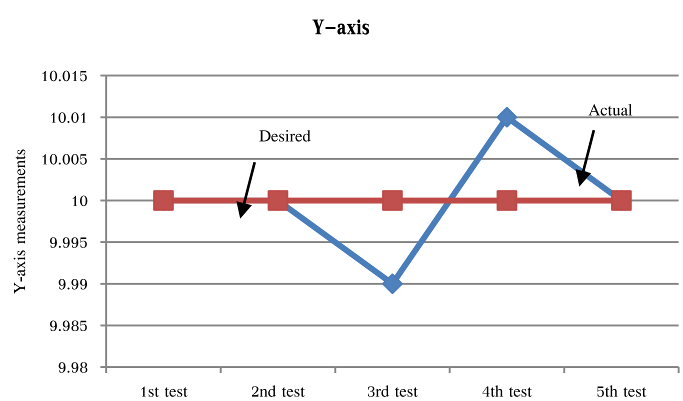


Fig. 13. Y-axis mesurements

The machine accuracy is got 0.02 mm from the experiment measurement results.

4.2 Machining Test

The machining test was carried out to observe the capabilities of the small-scle CNC machine. This machine is tested by cutting three different materails, aluminum, acrylic and wood, with different feed rates. But the same spindle speed and cuttign tool diameter are set to be machined the materials. Fig. 14 shows the cutting sample shape in aluminum with this CNC machine.

Fig. 14. Cutting sample shape in aluminum

TABLE 4
MACHINING TEST DATA

Workpiece	Aluminum	Acrylic	Wood
Tool	ϕ3 End mill	ϕ3 End mill	ϕ3 End mill
Spindle speed	3000 rpm	3000 rpm	3000 rpm
Depth of cut	1mm	1mm	1mm
Feed rate	20 mm/min	50 mm/min	100 mm/min
Machine time	5 min	2 min	1 min

(a) (b) (c)
Fig. 15. Machining test with CNC milling; (a) aluminum, (b) acrylic, (c) wood

Machining test was made by appropriate minimum feed rate. Fig. 15 shows the materials after being machining with this CNC machine. There are slightly different accuracies but it does not affect the requirement of machining process.

5 CONCLUSION

In this work, a small-scale 3 axis CNC milling machine was designed and fabricated with a low price. This proposed machine is easy to implement, inexpensive and comparable to the commericaly available machines. The components of CNC machine are selected to provide accuracy and simplicity within limited budget. The accuracy of the CNC machine body parts assembly has succeeded to achieve the objectives in precisely and repeatability goal. In future work, the Y-axis guideways of the machine are modifying to be able to machine more load of object and to increase machine rigidity. And aslo it is planned to do the stress analysis of the machine body stuructures.

ACKNOWLEDGEMENT

The authors wish to thank Dr. Khaing Thida and Dr. Swe Zin Nyunt for their guidance. This work was supported in part by a grant from Department of Mechanical Engineering, Thanlyin Technological University.

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